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How a Forest Disappears: Conversion of Forest to Nonforest Vegetation Following Wildfire

If you take a road trip through valleys and mountains in the western United States, you're bound to see the transition between the lower tree line and the vegetation below it, predominantly shrubs or grasses. Under a warming climate, these lower elevation forests are considered "trailing edge" forests because the boundary between forest and nonforest is expected to move upslope and northward.

"That boundary between forest and nonforest you see is a climate signal. Below that transition, the climate conditions are generally unsuitable for trees," says Sean Parks, a research ecologist with the Rocky Mountain Research Station (RMRS) in Missoula, Montana.

It's here, along lower elevation trailing edges, where conditions are becoming increasingly warmer and drier and where a forest's range is likely to shrink. Parks has been tracking the trailing edge of forests because this is where the risk of conversion from forest to nonforest is most likely.

"Most of our forests, especially trailing edge forests, are susceptible to fire," he says, "They're dry and there's a lot of fuel. So if we can identify where there's an elevated likelihood of stand-replacing fire, it gives us an idea of where we can do

The 2020 Castle Fire killed 100% of the trees, including giant sequoias, on this site in the Sierra Nevada, California. USDA Forest Service photo by Curtis Kvamme.

SUMMARY

Scientists are seeing an increase in cases where forest resilience is pushed beyond a breaking point. Within the last few decades, wildfires in the western United States have increasingly burned so severely that some forests are unlikely to return to their prefire state and may convert to different forest types or even to nonforested systems like grassland or shrubland.

Research ecologist Sean Parks (with the Aldo Leopold Wilderness Research Institute housed within the Rocky Mountain Research Station [RMRS] in Missoula, Montana) is collaborating with scientists and managers to understand why, when, and where severe wildfires are likely to occur and how they may lead to forest conversion. The evidence shows wildfire severity has increased over the last three decades and the trend is expected to continue into the future with changing climate. Forest conversion and loss is most likely along the lower-elevation trailing edges of forests in the western United States where conditions are becoming increasingly warmer and drier. Catalyzed by high-severity fire that eliminates tree cover, conversion becomes increasingly probable without viable seedlings. Wet years that are more favorable for seedling establishment are projected to become less frequent in dry forests.

Forest conversion presents a possibility of profound and persistent ecological change across forested ecosystems—changes that are likely to define future land management efforts. A framework for developing climate change adaptation strategies and potential management responses to forest conversion is emerging based on the concept of resisting, accepting, or directing change.

some work to prevent it when that inevitable fire occurs.”

In trailing edge forests, the higher the probability of stand-replacing fire (high-severity fire that kills most or all trees), the higher the risk of conversion.

Scientists are seeing an increase in cases where forest resilience is pushed beyond a breaking point. Within the last few decades, wildfires in the western United States have increasingly burned so severely that large forest stands are completely wiped out. Not a single living tree remains—and the forest is not recovering.

Prior to European contact in North America, many lower-elevation dry forests burned frequently but at fairly low severity. This frequent burning kept fuel loads low and limited the prevalence of stand-replacing fire.

“Now, we have kind of a triple whammy,” says Parks. “Our forests are not set up for success because we’ve taken fire out of the system and fuel loads are high. On top of that, climate change is resulting in more stand-replacing fire, and climate change is limiting the ability of seedlings to establish and survive.”

Even if seed sources are not completely burned up, climate conditions are increasingly unfavorable to seedling establishment and survival. This means that some forested landscapes are unlikely to return to their prefire state and may convert to different forest types or even to nonforested systems like grasslands and shrublands.

The extent and severity of wildfire is expected to increase with ongoing climate change, forcing difficult questions about how to manage forests into the future. Conversion of forests is challenging managers’ ability to balance the many values that forests provide, from recreation and timber production to wildlife habitat and water quality and quantity, not to mention carbon sequestration.

Parks, whose research focuses on disturbance ecology and fire science, is collaborating with other scientists and managers to understand why, when, and where severe wildfires are likely to occur as well as the conditions that lead to forest conversion. The results of their efforts offer insights about how to reduce the potential for forest conversion.

Wildfire 2.0: Bigger, more frequent, and more severe

Fire is a natural component of forest ecosystems, and at the same time, people have long influenced wildfire. Early Native Americans observed changes caused by fire and they understood fire could result in conditions favorable for supporting the wildlife they hunted. They learned how to use fire as a tool for managing landscapes to their benefit.

Today, as a result of a history of fire suppression and climate change, the influence of humans is contributing to troubling trends in fire behavior.

"The inevitability of fire is an important consideration," says Parks. "These forests are going to burn at some point, even without climate change. Our forests are not set up well for success because we have removed fire from many of these ecosystems for more than a hundred years, resulting in excessive fuels buildup."

As conditions have become warmer and drier, scientific evidence shows that the area burned by wildfire each year in the western United States has increased since the mid-1980s. Less clearly understood, and perhaps more important in terms of forest recovery, are trends in wildfire severity.

Because so much is at stake, Parks, in partnership with University of California climate scientist John Abatzoglou, undertook a comprehensive evaluation of trends in fire severity in four large ecoregions of the western United States from 1985 to 2017.

"It isn't really a question of where is fire more likely, but if a fire burns, what's the likelihood it'll kill most or all of the trees," Parks says.

The results show an eight-fold increase in area burned by high-severity fire—from 64,008 acres to 519,618 acres—over the three-decade span. The scientists

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—Sean Parks,
USDA Forest Service
Research Ecologist

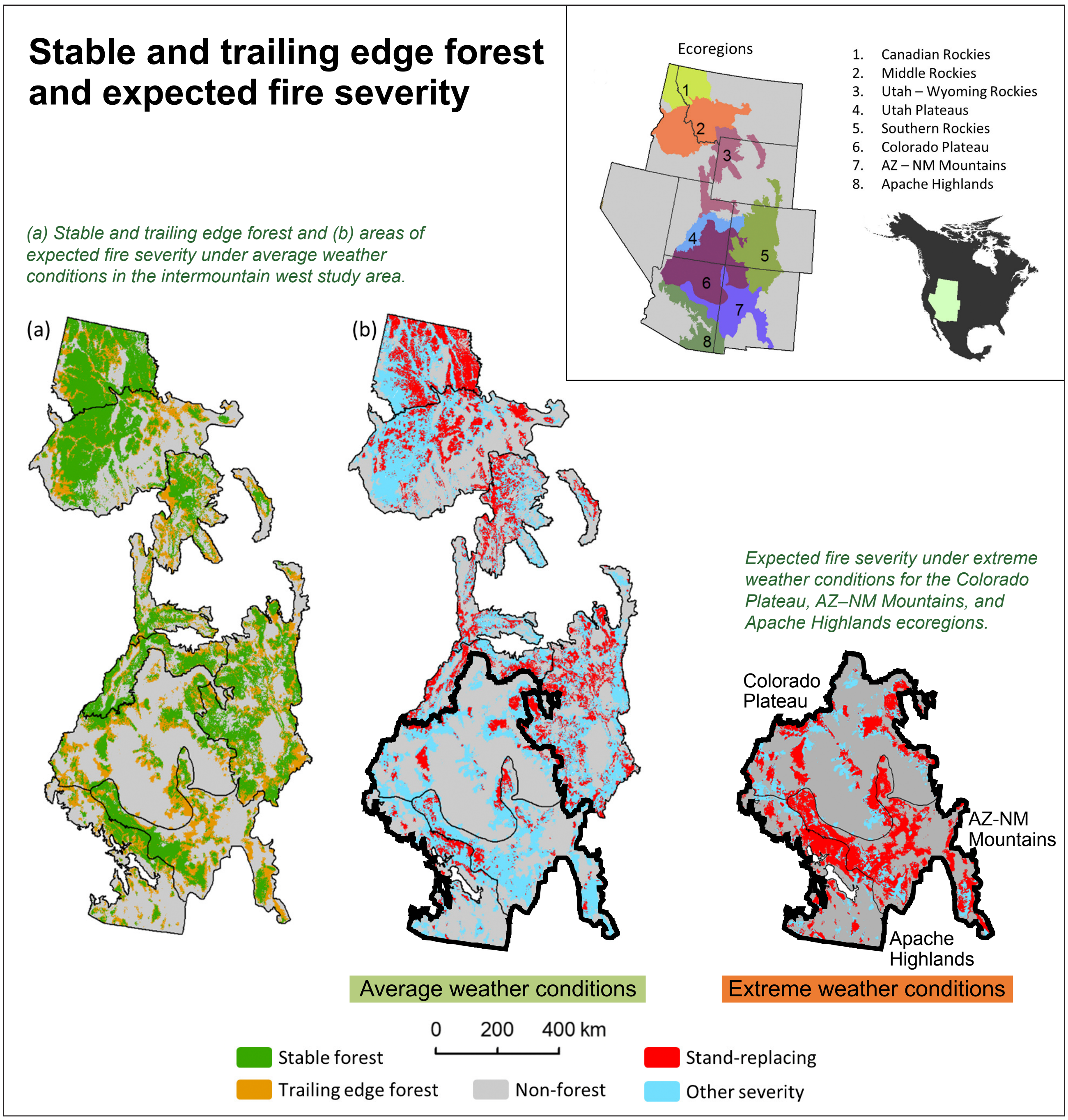
After two repeat high-severity fires (the 1996 Dome Fire and the 2011 Las Conchas Fire), this former ponderosa pine forest in northern New Mexico is now dominated by re-sprouting shrubs and nonnative grasses. Photo taken in 2016. USDA Forest Service photo by Sean Parks.

found that warmer and drier fire seasons correspond not only to high-severity fires covering more ground, but also to increasing levels of severity. These trends are expected to grow in coming decades along with the prospect of fire-driven conversions from forest to other vegetation types.

It's important to understand where stand-replacing fire is likely to occur now and in coming decades and one place to look is along the lower-elevation edges of a forest's range.

Tracking the trailing edge

In order to determine where forest conversion is most likely to occur, Parks and a team of RMRS scientists first identified where trailing edge forests are expected to be located in the intermountain west during the mid-21st century. Of the 189,190 square miles they mapped as forested in the study area, they estimate that nearly 36% will be trailing edge forest



(67,954 square miles). Within that area, they zoomed in on locations where stand-replacing fire is most likely and found that by the mid-21st century, 18% of trailing edge forest and 6.6% of all forest are at elevated risk of fire-facilitated conversion to nonforest vegetation.

But here's an important caveat. That scenario assumed that fire would burn under average weather conditions. What would the results look like under the more extreme weather conditions that are projected with changing climate? Fortunately, the scientists had data for a subset of the study area that allowed them to consider this question. They found that more than 44% of forest in the southwestern United States (Colorado Plateau, AZ–NM Mountains, and Apache Highlands) is considered trailing edge. Under extreme burning conditions, 61% of that trailing edge forest (17,375 square miles) and 30% of all forest in this region is at elevated risk of fire-driven conversion.

The scientists caution that these results should be interpreted carefully due to uncertainty associated with the modeling processes they used. At the same time, because stand-replacing fire is not the only threat to trailing edge forests—severe drought and insect outbreaks can also cause widespread die-offs that can catalyze conversion—they think their estimates may be conservative.

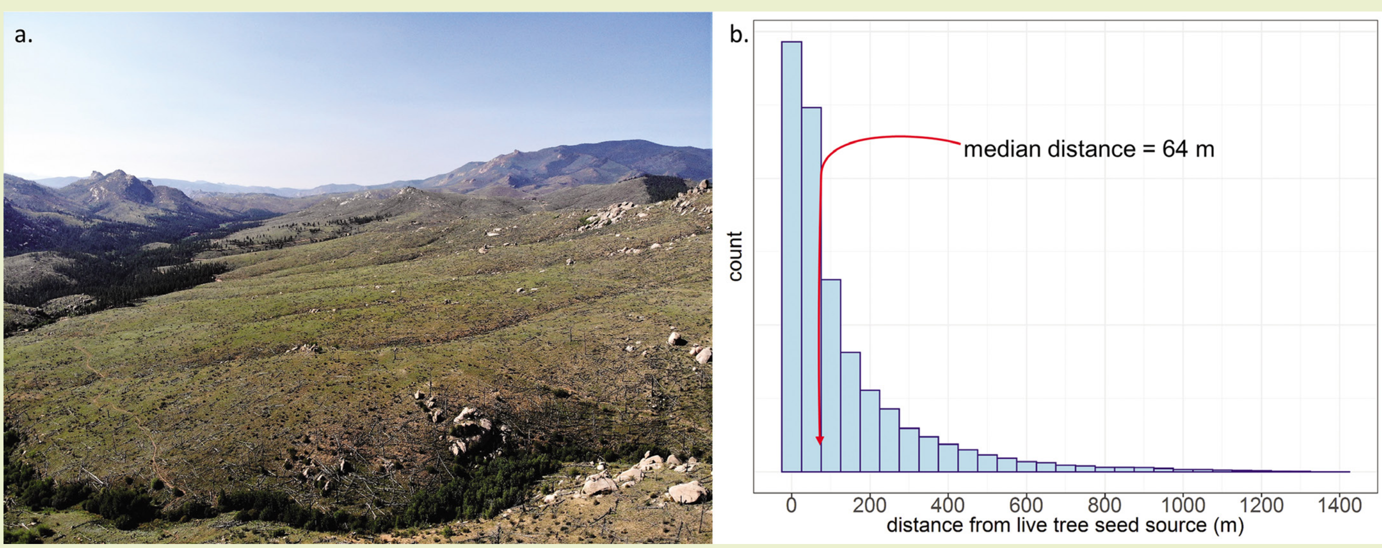
Crossing thresholds: No seedlings, no forest

Finely attuned to climate, temperature, moisture, soils, and topography, forests have evolved to persist across a range of conditions and recover from disturbance. Many forest species in the western United States have evolved traits that allow them to resist or withstand fire, and some even rely on fire.

But the size, frequency, and severity of fire today, along with warming and drought, are pushing some forests beyond the range of this adaptive capacity—beyond resilience and recovery.

Forest conversion begins with a stand-replacing fire that kills most or all trees. In the western United States, trends in fire behavior that are likely to accomplish this are largely attributed to the accumulation of fuels in forests where fire has been excluded and to climate change. Recent warming and drought also facilitate increased tree mortality before, during, and after a fire.

Once adult conifers are wiped out, recovery and regeneration are stalled without viable seeds. Live trees that could serve as seed sources are few and far between. The greater the distance between living seed source and the area burned, the less likely forest recovery will be.



(a) The Hayman fire in Colorado burned large, high-severity patches in a frequent-fire forest type. When measured 15 years later, sites less than 54 yards from tree seed sources were not recovering and now much of this landscape is dominated by shrubs and herbs. (b) Distribution of distances (meters) from high-severity patches to surviving tree seed sources within the burn perimeter. USDA Forest Service photo by Chuck Rhoades. Data from Jonathan D. Coop.

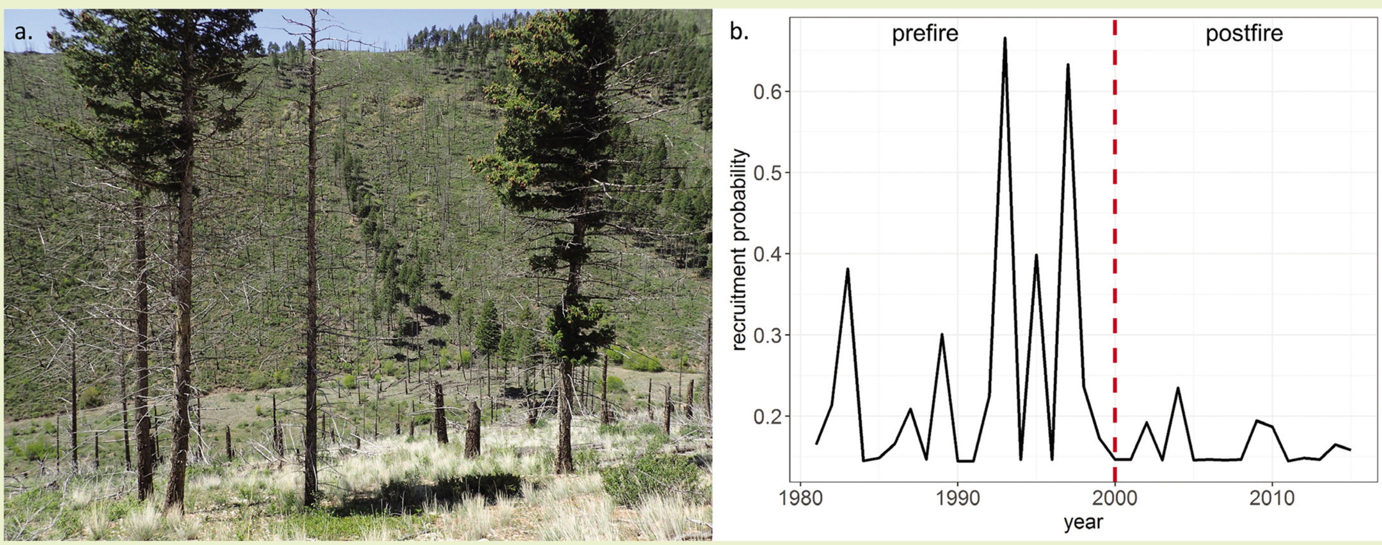
Crossing thresholds: No seedlings, no forest (continued)

Grasses and shrubs that can regenerate through resprouting are primed to gain a foothold. So begins the vegetation shift. A second fire fueled by dead woody debris caused by the first fire ensures that conifer seedlings and seed sources are further eliminated, clearing the way for the resprouters. Such short-interval fires are increasingly likely as fires burn more area each year (also see image of Las Conchas fire on page 3).

Should any conifer seed sources persist at this point, seedling establishment is hindered by warmer and drier postfire conditions. Parks and a team of scientists led by Kimberly Davis at the University of Montana looked at how annual climate conditions influenced postfire regeneration of ponderosa pine and Douglas-fir at low elevations across the West. They found that over the past 20 years, annual climate conditions have become increasingly unsuitable for regeneration at dry sites among the forests they sampled. The scientists conclude that “many low-elevation mixed conifer forests in the western United States have already crossed climatic thresholds beyond which the climate is unsuitable for regeneration.” The windows of opportunity for postfire recruitment in dry forests—wet years that are more favorable for seedling establishment—are projected to become less frequent in future decades.

Without the capacity for regeneration, the stage is set for conversion either to a different forest type, for example from pine to aspen, or from forest to grassland or shrubland. How long conversion endures through time depends on positive or negative feedbacks, which respectively promote or inhibit additional burning. Severe fire that begets severe fire is a positive self-reinforcing feedback loop. For example, high-severity fire can result in the accumulation of down fuels and dense vegetation regrowth prone to reburning and further prevention of recovery. On the other hand, slow fuel buildup after fire or a shift to less flammable species represents a negative feedback that might afford seedlings a fighting chance at establishment. But the effects tend to be temporary.

Fire-driven forest conversion results in major and abrupt changes to forest ecosystems—changes that are extensive and enduring—longer than the known historical recovery time.



(a) The Canyon Ferry burn in Montana, 17 years postfire, where postfire surveys suggest that there has been little to no recruitment at lower elevations. (b) Probability of recruitment at this site (Davis et al. 2019). USDA Forest Service photo by Kimberly T. Davis.

The size, frequency, and severity of fire today along with warming and drought are pushing some forests beyond the range of their adaptive capacity—beyond resilience and recovery.

Changing forests, changing paradigms

The possibility of increasing vulnerability to fire-driven conversion of forests in the Southwest is enough to keep Jack Triepke awake at night. As a regional ecologist with Region 3, he tracks ecological conditions on all 11 National Forests in Arizona and New Mexico.

He recently collaborated with a team at the USDA Forest Service Geospatial Technology and Application Center (GTAC) to analyze forest conditions across six decades of aerial photography on the Lincoln National Forest. They found significant forest loss along with substantial increases in fire and stress as change agents. As one of two southernmost National Forests in the Rocky Mountains, the Lincoln National Forest serves as a harbinger of forest change.

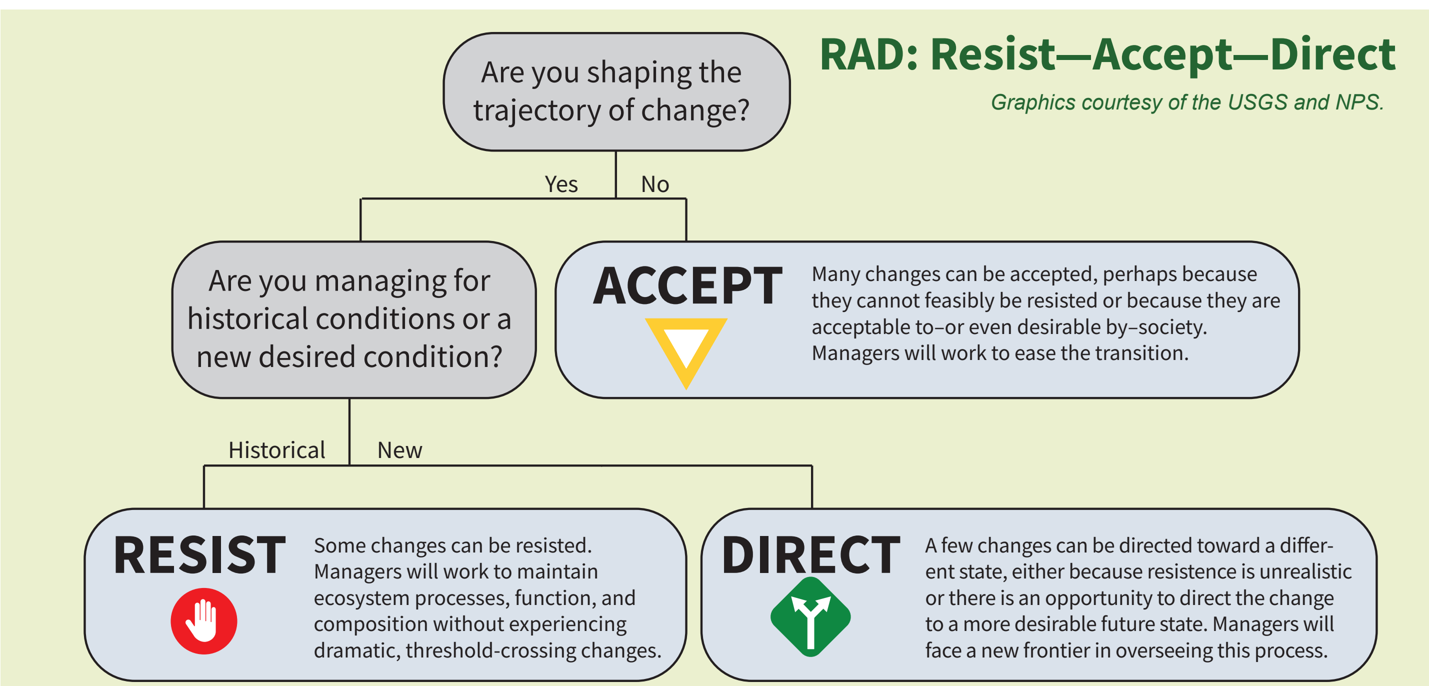
"What these new trajectories mean for how we can influence management to optimize long-term resiliency, habitat value, and watershed value—that's right at the top of my list of concerns," Triepke says.

Triepke is deep in the process of developing a climate adaptation strategy for the Forest Service Southwest Region based on a three-part concept of potential management responses to change: **resist**, **accept**, or **direct**.

Resisting wildfire-driven forest conversion means attempting to sustain existing forests by supporting prefire resistance or postfire recovery. For example, reducing fuel loads using prescribed burning or thinning can reduce the likelihood of severe fire that leads to forest conversion and to carbon loss in the long term. Similarly, allowing fires to burn or using prescribed fire under the right conditions can reduce fuel availability for subsequent fires.

Directing conversion uses management interventions to favor particular postfire outcomes aligned with human values or anticipated shifts in the potential for different vegetation types. In the Forest Service Southwest Region, for example, that could mean planning now to protect or enhance Mexican spotted owl habitat at higher elevations where the forest conditions they prefer are likely to persist in the future.

Parks favors the proactive approaches of resisting and directing in forests that have excessive fuel loads due to fire exclusion or outdated logging practices. "Let's prepare for that inevitable fire and make our forests more resilient to it," he says. At the same time, he



Graphics courtesy of the USGS and NPS.

recognizes that the pace and scale of management activities to do so would need to be stepped up by orders of magnitude. Parks also acknowledges that accepting change can be an appropriate response in many circumstances.

Where resistance (or direction) is futile or inappropriate, **acceptance** is a viable option. Accepting conversion concedes the replacement of forests by other vegetation types after fire without intervening and allowing for altered plant communities and ecosystem services.

"When high-severity fire rips through an area, we may not go in there and plant the trees that used to be there as in resistance, or plant trees we think will be there in the future as in direct," Triepke says. "We may decide to walk away and consider that a lower priority area and focus our efforts on higher value components like Mexican spotted owl habitat, for example."

Acceptance may become the default option for many lands due to limited access or lack of resources for proactive management, he says.

Triepke has been with the Forest Service long enough to witness a paradigm shift from managing primarily for timber production toward restoration and conservation. Now, even newer paradigms and strategies for managing land are needed. A paradigm shift toward more proactive management could reduce the need for reactive responses to wildfire in the West along with risks to forests, firefighters, and property.

With the possibility of profound change across forested ecosystems as a result of changing fire regimes and climate conditions, it's a tough time to be a forest manager.

"We've got our hands full," he says, "but we are grateful for people like Sean who are thinking about all of this."

It may not be long before an emerging climate adaptation paradigm is in full swing. But will it be soon enough?

KEY FINDINGS

- In just over 30 years, from 1985–2017, warmer and drier climate conditions in western U.S. forests have coincided with an eight-fold increase in area burned by high-severity fire. Warmer and drier fire seasons correspond with higher fire severity, which suggests that continued climate change may result in increased fire severity in coming decades.
- Warmer and drier conditions reduce the probability of forest recovery following severe fire where seedling establishment and survival is impeded. The probability of forest recovery also decreases as distance to live trees as a seed source increases. More stand-replacing fire means more area is limited by seed availability.
- Significant portions of forest, including ponderosa pine and Douglas-fir forests, in the Intermountain West are vulnerable to vegetation shifts because of climate changes and wildfire, and this vulnerability is projected to increase in coming decades as fires continue to burn more area under warmer, drier climate conditions.
- Under average weather conditions, study results show that by mid-21st century, 18% of trailing edge forest and 6.6% of all forest are at elevated risk of fire-facilitated conversion to nonforest in the intermountain western United States. In the Southwest under extreme burning conditions, 61% of trailing edge forest and 30% of all forest are at elevated risk of fire-facilitated conversion to nonforest.

MANAGEMENT IMPLICATIONS

- Increasing forest vulnerability to conversion to nonforest and the possibility of profound and persistent ecological change across forested ecosystems are likely to define future land management efforts.
- Management actions that reduce fuel loads, such as prescribed fire and thinning, can decrease the risk of stand-replacing fire and therefore reduce the probability of forest conversion. Managed wildfire (allowing fires to burn under less extreme weather) also has the potential to reduce fuel availability for subsequent fires.
- A framework of possible management responses is emerging based on resisting, accepting, or directing change (the "RAD" framework). Resisting forest conversion means attempting to sustain existing forests by supporting prefire resistance or postfire recovery. Directing conversion uses management interventions to favor particular postfire outcomes aligned with human values or anticipated shifts in potential for different vegetation types. Accepting conversion concedes the replacement of forests by other vegetation types after fire without intervening and allowing for altered plant communities and ecosystem services.

FURTHER READING

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SCIENTIST AND MANAGER PROFILES

The following individuals were instrumental in the creation of this Bulletin.

SEAN PARKS is a research ecologist for the Rocky Mountain Research Station and the Aldo Leopold Wilderness Research Institute in Missoula, Montana. He is interested in the relationship between fire and climate, fire-catalyzed forest conversions, restoring fire as a natural process, and spatial interactions between past wildland fire and subsequent fire events. Sean often uses data collected in wilderness to conduct his studies, thereby using wilderness as a natural laboratory. He holds a B.S. in environmental science and an M.A. in geography from the University of California, Davis, and a Ph.D. in forestry and conservation from the University of Montana. Sean's career with the Forest Service spans nearly 20 years. Connect with Sean Parks.

JACK TRIEPKE is Regional Ecologist and Air Program Coordinator for the Southwestern Region based in Albuquerque, New Mexico. Jack has conducted various ecological inventories, classification and mapping projects, and is active in developing and promoting landscape assessment tools to evaluate resource management and ecological sustainability. He has worked for the Forest Service for more than 25 years. Connect with Jack Triepke.

KIMBERLEY DAVIS is a research scientist in the Department of Ecosystem and Conservation Sciences at the University of Montana. Her work focuses on understanding how conifer forests of the western US respond to changes in fire and climate. Connect with Kimberley Davis.

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The purpose of SYCU is to provide scientific information to people who make and influence decisions about managing land.

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